NOTE TO PAPER REVIEWERS

Please note this text in blue in not intended as part of the abstract but only as background information. I was not able to upload these comments in full using the on-line system into "**Special Instructions or Comments".** Please excuse me if these comments are either obvious or out of place. They are only intended to help.

Since Huygens landed there has been ever increasing interest in exploring Titan and hot air balloons are seen by many as ideal vehicles. In making plans it is only natural to look to the major laboratories and centers that have created almost all Solar System probes. The overall system from in-situ measurements to data received on Earth could only be managed by such a major organization: the balloon is only one component no matter how crucial. But when considering the balloon itself, perhaps one should not think of a Titan balloon as a spacecraft. Instead perhaps it should be viewed as a balloon that happens to arrive in a spacecraft. This paper is an attempt to look from this perspective and draw from the knowledge of the some of the world's preeminent balloon experts. If, as evidence suggests, Titan is very earthlike, then terrestrial balloon experience it highly relevant.

Two of the authors are unknown in the planetary exploration community, but world leader in piloted balloons. Don Cameron is without doubt the world's preeminent designer of hot air balloon envelopes. Among innumerable achievements over more than thirty years, he designed the balloon envelopes used for the two manned flights around the world made to date. Similar Don Day is very highly regarded in the balloon community and inter alia is the forecaster for all scientific balloon flights undertaken by Kirtland Air Force Base in Albuquerque.

I was lucky enough to make two previous oral presentations at IPPW 4 in Pasadena and 6 in Atlanta. For background see http://nott.com/Pages/about.php Regarding work on Titian balloons please see the papers www.NOTT.com/papers in particular the Titan Sky Simulator.

Thanks -- Julian

ABSTRACT

AN ADVANCED DESIGN FOR A TITAN BALLOON

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Ever since Cassini arrived at Saturn and the Huygens Probe descended onto Titan, Titan has emerged as an ever more interesting place with corresponding continuously growing interest in a follow-on mission. A balloon appears to be an ideal vehicle to explore Titan. It would carry cameras and instruments like a Mars Rover. But while the two existing Mars Rovers have, combined, traveled less than thirty miles in six years, a balloon could cover thousands or tens of thousands of miles. In addition is has emerged that Titan has weather and other conditions that are dramatically better for balloon flight than provided by the Earth's weather and conditions. Balloons emerge as very attractive for Titan in-situ exploration. Conditions are of course still partly uncertain, see below.

It is very beneficial for a Titan balloon to be able to change altitude at will. It is obviously a major advantage for science observations if the balloon can view wide panoramas at altitude and descend to take close-up pictures and to lower instruments to touch both solid and liquid surfaces directly. Being able to change altitude also means the balloon can use light winds to travel slowly at low altitude for observations or climb into stronger upper winds to travel long distances. And of great importance it allows for substantial steering. The extent to which contemporary terrestrial balloons are steered very effectively, simply by changing altitude is not fully appreciated outside the field. It will be impossible to know exactly what Titan conditions will be offer until the balloon actually arrives. So the more flexibility the balloon can have the better, perhaps to fly above certain weather or fly below icing conditions or avoid bad weather altogether by steering.

Balloons have long been proposed for Titan, but serious interest in hot air balloons began followed the seminal 2005 paper [Jones, Fairbrother et al] which suggested that a Titan hot air balloon could be heated by the surplus heat from the radioisotope thermoelectric generators used to power all craft at the outer planets where sunlight is too weak for solar cells to be effective.

But since then there has been only limited change in the basic concepts for such a balloon. This paper describes in detail a system that hopefully substantially improves over the 2005 proposal.

The paper will include:

- A detailed description of a highly insulated balloon envelope which used multiple fabric layers giving sufficient insulation that it can be heated by the surplus heat from the newly developed Advanced Stirling Radioisotope Generator. This has several major advantages. It allows for a lighter balloon system and requires only one eighth [depending on the design] of the amount of radioisotope material, a very scarce and expensive resource. In addition a smaller highly insulated balloon has a higher buoyancy per unit volume. This of itself gives greater resistance to gusting. In the design described the full hydrostatic pressure at the top of the balloon is carried to the mouth following the classic Cameron "Coke Can" design. This concept has been tested in innumerable balloons flown over three decades. This give pressure at the mouth and this too is very valuable to resist any atmospheric gusting. As yet another feature to resist gusting, the balloon will incorporate a "Base Parachute", a fabric check valve mimicking the extremely reliable crown parachute in universal use in hot air balloons for several decades. Finally a smaller, hotter balloon has a smaller displacement and correspondingly lower inertia, yet another beneficial quality when encountering a gust or other unexpected weather. Also this smaller inertia and cross section area mean that it can more easily be moved sideways if it is fitted with propellers as has sometimes been proposed. While such a balloon might be thought to be complex, it is no more so than such balloons as the two piloted balloons which successfully flew around the world and trivial in complexity compared to a space craft. Moreover this kind of design can be quickly and very inexpensively prototyped.

  As well as all these advantages, substantially smaller balloons might allow a mission with a smaller rocket or allow a balloon as a "Hitchhiker Payload" on a large mission or allow two or three balloons to be sent on a mission where one was originally planned.

- A detailed thermal analysis of the balloon envelope design, based on the extensive physical and theoretical thermal modeling already completed [Colonius, Nott, et. al. 2009].

- Insights into Titan weather extrapolated from terrestrial experience. Currently the best assumption is that Titan is rather earthlike. So the practical experience gained by forecasters specializing in balloons from the more than four million piloted flights made over the last five decades by terrestrial hot air balloons is invaluable to draw on.

- A description of an emergency heating system. As mentioned there will be uncertainties about Titan conditions even after a balloon is flying there. The balloon described is very much better to survive unexpected weather than other concepts. But the paper will also include a detailed description of an emergency heat source using hydrazine or a non-toxic, low temperature tolerant, very high energy density, NOFBX monopropellant (in flight experiment development for launch to Space Station in 2012 and in prototype ascent engine development and test for the Mars Sample Return Mars Ascent Vehicle) to allow the balloon even better ability to survive encounters with turbulence, downdrafts and other unexpected conditions. Despite almost 230 years practical experience, terrestrial balloon operators still encounter weather which has never been experienced previously. Assuming, as is currently anticipated, weather like everything else on Titan is very earthlike, unexpected events will be encountered. With or without the features to add robustness to the balloon described above, an emergency heat source is seen by some terrestrial operators as improving reliability perhaps by an order of magnitude or more, although this is not fully quantifiable.

- A detailed description of a method of air-launch inflation, meaning that the balloon fills, heats and flies away while falling through the atmosphere. This extrapolates from 50 years experience of contemporary hot air balloon operations including thousands of hot air balloons that have been successfully air-launched.

In all it is hoped to present a design with substantial benefits over previous Titan hot air balloon proposals, over any proposal where the balloon flies at a fixed altitude and any design such as an AM, mixed gas and hot air balloon, where the balloon uses a lifting gas which will inevitably suffer lifting gas loss over time.

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